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INTELLIGENT LOAD MANAGER (LOADMAN)

Application of Expert System Technology to Load Management Problems in Power Generation and Distribution Systems

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Prepared for
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SUMMARY

BACKGROUND

This document is the Phase I Final Report for research conducted by Technology Applications, Inc. (TAI) under the Department of Defense (DOD) contract number DAAK70-87-C0058, entitled "Intelligent LOAD MANager (LOADMAN)." This project was funded as a part of the Small Business Innovation Research (SBIR) program and is a feasibility study aimed at using artificial intelligence (AI) techniques to explore the implementation of an expert system serving as an intelligent power systems manager. In developing the demonstration prototype, the emphasis was placed on clarity and the use of generic techniques which would allow future extensions and modifications. Phase I was comprised of four tasks:

1) Develop Knowledge Representation(s)
2) Develop Reasoning Mechanism
3) Develop Demonstration Prototype
4) Project Management and Documentation

Tasks 1 and 2 involved detailed domain analysis, evaluation of the prospects of an expert system in this domain, and the steps that should be taken to make further development of the load management system a success. Task 3 involved the implementation of various parts of the system to demonstrate the feasibility of using AI techniques to solve relevant problems. Task 4 involved the production of this report which has been written with an emphasis on domain analysis and future development strategies.

Task 1 - Developing Knowledge Representation(s)

Work on this task started with discussions (both internal and with Army personnel at Ft. Belvoir) of the kind of problems that the Army would like to solve. The various physical objects in the domain and their characteristics were discussed (e.g., generators, telephones, radio communications equipment, distribution equipment, etc.). Future extensions to the system to make it handle other problems were also discussed so that the knowledge representation could be designed on a generic and broad basis.

A classical object-oriented knowledge base (i.e., objects/slots/facets) was chosen to represent data about the mission and declarative knowledge about the various loads, sources, and distributors. In other words, all entities in the problem domain are represented using objects. This has the advantages of modularity, conciseness, and natural representation. Also, an

object-oriented representation allows extensions to be made easily and naturally.

Task 2 - Developing the Reasoning Mechanism

Various example problems and relevant solution methods were used to consider different reasoning mechanisms. The general problem is one of system configuration and loading within a set of constraints. The nature of the solution is iterative, so part of the reasoning mechanism is better implemented using conventional LISP code. However, for the system to be generic and extendible, rule-based reasoning is a must. Thus, a combination of conventional programming and rules is used to represent and process the various constraints. For example, there are placement constraints which specify some undesired positional relationships between two camp objects or undesired location of objects with respect to the camp layout.

Task 3 - Developing the Demonstration Prototype

A demonstration prototype was built during the course of the project to explore further the technical feasibility and practicality of the chosen AI techniques. In-house examples and test cases were used to develop and test various parts of the prototype. This effort helped the project team appreciate the need for accurate data in terms of the equipment used and also in terms of the Army's priorities, policies, and procedures. The unavailability of knowledge/data regarding the Army's power generation/distribution planning and decision making is the main concern that has arisen out of the prototype development effort. However, the prototype demonstrates convincingly, with well-chosen examples and reasonable assumptions (where there were gaps in the knowledge), that an expert system could be built to solve the load management problems in a military setting.

Task 4 - Project Management and Documentation

The project report was prepared with an emphasis on establishing the general philosophy and feasibility of the idea. Shortcomings of the present methods and equipment have been clearly pointed out. Ways to handle these problems and future development of the distribution system have been suggested. The final report begins with an analysis of the domain and assessment of its suitability for an expert system. Then the conceptual system design of the Phase II implementation is discussed. It is recommended that this be carried out in two stages - as an off-line advisory system and then an extension of such a system into an on-line autonomous system. The next section contains the description of the demonstration prototype. This is followed by the project conclusions and recommendations.

SUMMARY CONCLUSIONS AND RECOMMENDATIONS

Domain analysis and the development of the rapid prototype system have revealed that the implementation of an expert system is ~~indeed~~ possible if some preliminary work is done to standardize the equipment and establish clear guidelines for load shedding and other decisions. This effort should be carried out (even if the expert system is not implemented) to ensure reliable, efficient power generation and utilization and to reduce the likelihood of costly mistakes. ~~TAI~~ The contractor is convinced that the technology is valuable to the Army in terms of improved inventory handling, optimized power usage, and operator training, all leading to more effective mission completion. Keywords: Artificial intelligence; Electrical loads; Load control; Power engineering; Systems management; Electric power generation; Electric power distribution (edc)

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SECTION 1

INTRODUCTION

1.1 BACKGROUND

This document is the Phase I Final Report for research conducted by Technology Applications, Inc. (TAI) under the Department of Defense (DOD) contract number DAAK70-87-C0058, entitled "Intelligent LOAD MANager (LOADMAN)." This project was funded as a part of the Small Business Innovation Research (SBIR) program and is a feasibility study aimed at using artificial intelligence (AI) techniques to explore the implementation of an expert system serving as an intelligent power systems manager. This investigation addresses both planning issues (e.g., power generation/distribution, logistics, and supply) and tactical issues (e.g., campsite power distribution layout and proper load shedding following a generator casualty).

Military units are heavily dependent on electric power which is normally provided by diesel or gasoline generators. The critical nature of the environment calls for a Power Generation and Distribution System which is highly flexible and reliable. The power should be distributed and used efficiently, and the equipment requirements must be minimized so that the logistics burden is reduced.

1.2 PROJECT OBJECTIVES

The objective of this project/report is to explore the idea of using new (expert system) computer technology in this domain, thereby facilitating the application of load management techniques to perform various functions like load shedding and duty cycle scheduling. This controlling system should be designed so that it does not totally break down under adverse conditions. Instead it should be able to maintain a level of performance that is as good as the operating conditions will allow. Since the system has to optimize power utilization in degrading circumstances, it will have to drop loads and/or operate some loads at reduced power. Such decisions are important because they can affect the success of the mission. So the system will have to be designed according to well-defined Army policies and procedures.

1.3 GENERAL PROJECT COURSE CHANGES

The project work started with a discussion of the kind of problems that the Army would like to solve. At this time, the Army contact personnel indicated that the system be designed initially as an off-line advisory system because of the additional cost of installing sensors and control equipment to the power equipment. The system possibly could be converted to an on-line autonomous system in a later phase. It was decided that the system should be designed as a constraint representation and management system that would be sufficiently generic so that it can be expanded to include other applications. A literature survey was then performed to study other systems that tackled similar problems. Even though these systems were not generic enough for direct application, they provided numerous pointers that helped in developing suitable knowledge representation and generic scheduling techniques.

The implementation of the Demonstration Prototype was then begun. In-house examples and test cases were used to develop and test various parts of the prototype. The prototype had some gaps in its knowledge about the domain because of the absence of "real" experts who understood and knew how to solve these problems. Sufficiently accurate test cases were not available and it became very difficult to proceed with the completion of the prototype.

At this stage, the project team was informed that a demonstration proving that advanced computer techniques could be used to solve load management problems was all that was expected of this phase of the project. The project team then proceeded to identify and document the missing knowledge elements in the problem domain and the various steps that should be taken to ensure that the successful development of an expert system was indeed possible.

1.4 REPORT ORGANIZATION

The rest of the report is organized as follows. Section 2 discusses the problem domain, its limitations, and its suitability for an expert system under current conditions. It also recommends issues to be analyzed and steps that should be taken to standardize the domain to the point where the knowledge is complete enough for incorporation in an expert system. Section 3 explores further development of the LOADMAN system and details the development stages and discusses the feasibility of the various features. The prototype design and implementation including the hardware/software selection, problem solving strategies, knowledge representation, and programming methodology are detailed in Section 4. Section 5 discusses the conclusions and recommendations.

SECTION 2

DOMAIN ANALYSIS AND FINDINGS

Power generation and distribution systems are an important part of the equipment that an Army unit needs in order to successfully complete its mission. Power requirements and importance of the different loads vary depending on the function of the unit - reconnaissance missions, field hospitals, etc. Also, certain other factors like the weather, location of camp, and the terrain could alter the power generation and distribution inventory and/or power requirements.

Apart from these specific optimization difficulties, the problem is complicated by the fact that there are no established practices or procedures for power generation and distribution planning. Most equipment (loads) is designed to be operated directly from a dedicated generator, and so distribution boxes that distribute power from larger generators to a number of small loads do not exist or are not widely available as standard equipment. Also, it is impractical to transport and maintain large numbers of smaller generators. Current practice indicates that ad hoc switch boxes and distribution equipment are developed and often used without proper regard for safety and/or technical soundness.

The domain characteristics and its suitability for an expert system solution are discussed below. Then, the various factors that could affect the dependable and fail-resistant operation of power generation, distribution, and utilization equipment will be addressed. The policy decisions that should be made regarding backup facilities, redundancy, and safety margins will be outlined. These should be quantifiable so that the reliabilities of various power system configurations can be calculated and compared. All these steps will make it possible to recommend reliability factors for various kinds of missions (based on their importance).

Such systematic study and evaluation of power distribution systems is routinely done in almost every industry to ensure reliable operation and optimization and should be of equal merit and value in improving the effectiveness of the Army units. A power system failure can render a unit useless and adversely affect the outcome of the mission.

2.1 ASSESSMENT OF THE PROBLEM DOMAIN AND ITS SUITABILITY FOR AN EXPERT SYSTEM

This assessment is based on the information gathered from Army contact personnel, equipment and configuration data/manuals made available, and a JTX trip report.

Several devices are in use by units attempting to solve power distribution problems. While most loads were designed to operate with a dedicated generator, field personnel usually connect them into some kind of a distribution system. Few military standard distribution boxes are available and units that need others have them constructed. These fabricated distribution boxes occupy a spectrum in terms of their usefulness and safety.

All this raises some questions about the suitability of the domain (as it now stands) for implementing an expert system. The success of expert system development depends very much on the ability of the domain to conform to the some basic requirements. If the domain is deficient in some areas, they should be addressed before the expert system is actually attempted. Discussed below are two requirements which may not be satisfied by our problem domain.

Availability of experts. A widely recognized precept is that a problem is suitable for expert system implementation when there is at least one human expert who is substantially better at solving the problem, does it routinely and, therefore, has the knowledge and experience to understand the real problems, to generate solutions and to make (usually correct) decisions.

Availability of test cases. Knowledge engineering is often carried out by watching the experts actually solve problems. Experts tend to take details for granted and omit them while describing the solution process. The use of test cases and the observation of the experts more accurately brings out the solution process and the knowledge used. These test cases should also be used for testing the system as it is developed.

Since the current domain does not have such experts (as gathered from Army comments and reports) nor the requisite test cases, the next best thing is to form a body of knowledge that is derived from the theory of power generation and distribution systems. Also, the lack of methodical load shedding and scheduling procedures calls for establishing some standard practices which could then be followed and monitored to ensure the safe and reliable operation of power distribution systems. Only after the equipment and the procedures have been defined can an expert system be built to perform the various configuration and load balancing tasks effectively. (To be precise, such a system would be labeled a "knowledge based" system rather than an "expert" system.)

2.2 FACTORS AFFECTING RELIABILITY

2.2.1 Equipment Specification and Design

Power generation equipment. Power generation equipment used by the Army falls mainly into two categories - diesel and gasoline. They are designed for various power levels with facilities for varying the output voltage. The maintenance requirements of these generators vary and there are other advantages and disadvantages to both types. A study should be made of the various factors, and guidelines should be established for the appropriate use of each. Various considerations are briefly discussed below.

The end-user confidence in 1.5 to 10 kW gasoline generators is low. They are, in practice, difficult and time-consuming to maintain. Wherever they have to be used, personnel provide for two sets to ensure that if one set became Not Mission Capable (NMC), the other one could be used in its place. The cost effectiveness of this approach should be examined and the substitution of these with diesel generator sets should be considered. Diesel-type generators, mounted on trailers with switch boxes, were the ones most popular with field personnel whose opinion is that these are easier to operate and maintain. However, the noise generated by the diesel generators is greater and provision of quieter designs may be considered.

Some smaller (3 kW) generators do not have "breakerless" ignition kits installed, and starting the generators poses a problem due to moisture in the ignition system.

Power distribution equipment. Loads need to be switched between power sources for various reasons such as maintenance, breakdown of generators, etc. In such cases, a fast, safe and efficient change-over is necessary. This is especially important where the loads cannot tolerate even a temporary power interruption. Switch boxes and generation equipment must be designed to meet these requirements so that the frequent loss of critical services (which might take a few hours to be reestablished) is avoided. Even automatic power backup facilities may be appropriate for certain critical services and the provision of such facilities must be seriously considered. This is discussed in detail in the next sub-section.

A new, easy-to-understand method should be devised for initial connection of the power cable to the generator. Currently, the correct method of connecting these cables is confusing. Numerous pieces of equipment have been damaged or destroyed due to improper connections. Built-in safeguards that try to prevent misuse and improper operation of equipment should also be considered. Matching sockets and plugs may be designed into the equipment and connecting cables to ensure proper connections. Such technology exists in the power industry.

In this context the DISE system, which is an attempt by the Army to design a standardized distribution system, will be discussed. It consists of the Feeder System, Distribution System, and the Lighting and Receptacles System. From the information obtained, the system appears to be incomplete in some respects. For example, all single-phase outlets are rated at 20A, yet a number of single-phase loads which draw more than 20A have been identified.

2.2.2 Equipment Configuration

The reliability of a power system may be improved by increasing the number of independent power sources. The more generators that are available, the lesser the chance of all of them failing at the same time. High-powered and/or sensitive equipment will benefit from their own power source which will eliminate any power fluctuations due to start up or operation of other equipment. The nature of such equipment will sometimes dictate a location close to the generator. For example, X-ray equipment works better when it is located close to the power source so that it can obtain sufficient voltage with minimum fluctuations.

Also, the characteristics of the power network also affect the reliability. For example, if the loads were all strung together in tandem, there would be more failures than if they were all connected directly to the distribution box forming a star network. This is because the failure of a cable would result in the failure of just one of the loads in the case of the star network.

A related development is the work that has been done in the area of information/data distribution networks. Various configurations like the STAR, RING, BUS, etc., have been investigated for the inherent reliability and tolerance in the event of failures. Such information could be used modulated by other constraints for a safe, functional and effective power distribution system.

2.2.3 Backup Equipment

Alternate power sources are mandatory in most industries, so as to bring the regular sources down for maintenance checks. These alternate sources would also be available as backups in case of a failure. They are usually of lower capacity (for providing just the minimum services necessary). Related issues are discussed below.

When an alternate power supply ought to be provided may depend on one or more of the duration of the mission, type of generator, climatic conditions, type of load(s), etc. For a short mission and a reliable generator, an alternate may not be warranted. On the other hand, a long mission under severe weather conditions may require 100% redundancy. The rules and the exceptions should be clearly stated so that they can be incorporated in the expert system to allow it to plan for alternate sources. Mean-time-

between-failure data and mission criticality estimates could support this decision making process.

How much power ought to be provided would depend on the demands of loads which are absolutely essential to the success of the mission. Such loads should be specified so that the amount of alternate power necessary may be calculated. For example, most signal units need power 24 hours a day. The expert system can use such information to make the necessary calculations and provide for the alternate sources while preparing the inventory requirements.

How quickly should the change-over be accomplished clearly depends on the ability of the load to become functional once the power is interrupted. Full automatic backup may be necessary for critical and not-easily-reestablished equipment. For example, some communications equipment could be off-the-air anywhere from 1 to 24 hours once the power is interrupted for any reason and a break in communication occurs. The quality of backup facilities that should be made available for various categories of loads must be defined. The expert system can use this information to plan for the necessary backup equipment.

2.2.4 Use of Equipment

Policies and procedures need to be established for the proper use of power systems equipment. Personnel should be specially trained to work with generators, switch boxes, distribution boxes, and the various loads. This will prevent accidental misuse of equipment. For example, in one of the JTX's, a gasoline generator was mistakenly filled up with diesel fuel.

Guidelines for the proper loading of the generators should be established and then the expert system could monitor the load and issue a warning when the load is too high or too low. This is important because improper loading of the generator can cause "wet stacking" (which refers to the presence of unburnt fuel in the exhaust and the cylinders). This was found to be a common occurrence at most sites. It affects the efficiency and reliability of the generator.

Personnel should be trained on electrical safety procedures. Improper or insufficient grounding of generators was found to be a common problem. For example, cable connections to light sets were not covered in one of the missions and this would have posed a serious hazard if it had rained.

A list of non-military equipment that may be used should be established. Currently, household extension cables and appliances are widely used and may be loading the various outlets beyond their rated capacities.

2.2.5 Maintenance of Equipment

Power systems reliability also depends on the proper maintenance of the generators. Procedures and policies need to be established for the proper maintenance and checks on equipment. The availability of tools, parts, and trained personnel to repair generator equipment is important. Currently, proper maintenance is not performed at most sites due to various reasons such as nonavailability of switch boxes that will ensure uninterruptible supply of power and/or backup generators. In fact, in one case a generator became NMC at the beginning of the mission due to leaking oil seals and could not be repaired due to lack of repair parts.

The expert system can be designed to keep track of all maintenance related information and alert the user when checks and service becomes due. Also, the inventory planning part of the system could recommend the repair parts that would be needed for a particular set of generation and distribution equipment. But first, the guidelines must be compiled and made available to the expert system designer.

2.2.6 Equipment Interaction

Operation of two heavy loads simultaneously or the starting of loads that produce power surges while another heavy load is operating can produce undesirable results. Currently, personnel try to avoid these situations from experience. Most units are vulnerable to such load combinations but they are not very well documented. The power surge that is created by each piece of equipment and information about loads that should not be (need not be) operated simultaneously should be documented.

If these operational requirements are established, then they can be incorporated in the expert system which would then be able to monitor and regulate the operation of various loads.

SECTION 3

LOADMAN - A FEASIBILITY STUDY CONCEPTUAL SYSTEM DESIGN

A portion of the Phase I efforts was devoted to establishing the general philosophy, approach, and feasibility of the LOADMAN expert system. The project team's emphasis was on stretching the mind, evolving ideas, and drawing up a development and implementation plan for Phase II. Thus, there was an exploration of ideas and problem solving strategies which are described in detail in this section. This section will describe our vision for further development of the project and the expected benefits of an operational "LOADMAN" expert system were it to be fully implemented. The purpose is to suggest various problems that could be solved by the computer system and elicit feedback as to the usefulness/importance of the various features. One of the advantages of the object-oriented representation used herein is that once the domain has been represented in the knowledge base, incremental development of various specialized applications is easier.

3.1 LOADMAN - DEVELOPMENT STAGES AND EXPANSION POTENTIAL

LOADMAN is a constraint management and planning system that will be capable of solving power distribution problems in battlefield settings using knowledge-based techniques. Although limitations exist (as described in the previous section) in the present condition that require "first time engineering" efforts not directly related to expert system design, LOADMAN can serve as an infrastructure or supporting environment to foster resolution of these issues. Further, the LOADMAN conceptual design presented here presumes successful resolution of the open engineering and procedural questions and then provides "placekeepers" for the various knowledge elements expected to be derived from the first-time engineering effort.

Current battlefield environments have limited sensor capability and no remote control capability. However, future enhancements to current equipment, such as frequency-modulated power lines for remote control and the addition of sensors for monitoring of power equipment, are possible which would greatly enhance the capabilities of the system. In order not to prematurely limit the project capabilities as well as be sympathetic to current operating conditions, the project should be developed in stages. The first stage will work with no sensors and with manual input/control. At the end of this stage, the system will be an off-line advisory system not assuming any direct control of the equipment. It should then be capable of providing logistics planning advice (how many generators, distribution boxes, and

cable) and assisting in the layout and the manual operation of the campsite power system. The second stage will add sensors and control capabilities. At the end of this stage, a totally autonomous system will be built that is capable of solving most power distribution problems without any help from the user. LOADMAN would then provide generator health monitoring, power distribution monitoring and control, and casualty reconfiguration. In this fashion, the expert system is developed initially as an advisory system to help standardize the domain and play a useful logistics role while setting the stage and gathering knowledge for the autonomous system.

Since all mission details and equipment data is stored in the system, the system can be extended to perform a variety of other tasks by adding the appropriate knowledge incrementally (as needed). Thus, the system can help in ordering the inventory, planning the layout, monitoring the distribution system, and reconfiguration and control in case of any failures or casualties. There are other uses not connected with the actual mission, such as training personnel to perform the various tasks when the system is not available. The system could also be enhanced and extended to keep track of maintenance and repair information and an inventory of spare parts. This is especially important in the case of longer missions when equipment will have to be pulled off for maintenance to ensure reliable operation. Explanation facilities and hypothetical reasoning should also be introduced so that the user can query the system as to reasons for the various decisions and to ask "What if?" questions.

LOADMAN should have a "curator" facility that allows the system "custodian" to access and modify various parts of the expert system. The curator facility will be extended to facilitate creating and editing of rules, generation of reports (e.g., a listing of standard Army power sources), and examining and modifying knowledge bases.

The system can eventually be used for logistics support (procuring, maintaining, and transporting equipment to take for a specific mission), monitoring of power generation and distribution equipment, prediction of malfunctions, and reconfiguration of equipment. For example, the system may detect that it is about to lose a diesel generator or about to shut one down due to fuel shortage. It is here that any advice on system reconfiguration will be valuable. The sequence of events begins with event detection. This is usually detection of a measurement that violates a set-point (threshold value). The expert system is triggered to begin analyzing the situation and generate candidates for replacing the failed (or soon-to-fail) equipment. This is followed by the ranking of such candidates for best fit. For example, a consideration in the selection of a generator is its capacity with respect to the capacity needed. If the generator capacity falls short of the needed capacity, it would mean shedding some loads. On the other hand, if the generator capacity is much higher than the needed capacity, there is the threat of "wet stacking." This refers to the collection of unburnt fuel in the exhaust when the generator is operated

continuously at loads considerably less than full load. The reliability and efficiency of the generator is adversely affected in these circumstances.

Load shedding based on priorities needs to be carried out when a generator fails and a replacement with similar capacity cannot be found. To avoid much reconfiguration and/or load shedding, diesel generator health monitoring may be performed on an on-going basis so that the generator may be brought down for repairs/maintenance during periods of reduced demand. Health monitoring of generators involves testing for overheating, overloading, and failures. Dynamic load balancing based on operating conditions such as weather, enemy threats, casualties, etc., is yet another role that can be played by the expert system.

3.2 STAGE I OBJECTIVES

Based on the needs outlined in Section 2.1, the initial object of Stage I should be to establish the domain knowledge. Therefore, Stage I should be begun by concentrating on specifying equipment, establishing policies and procedures for backup equipment, and establishing priorities for the various loads. Then the system can be built to plan inventory requirements, configure the equipment, perform load shedding when necessary, and perform duty cycle scheduling for heavy periodic loads. All these applications should be implemented with an emphasis on maximizing efficiency and reducing the logistics burden. Graceful degradation in all of these areas is necessary when the system is working under suboptimal conditions (i.e., when an optimal solution cannot be formulated and some compromises have to be made). Brief descriptions in the following paragraphs describe what is planned in the specified areas.

3.2.1 Load Classification Scheme

To support computerization, all loads should be classified into different priority levels. We recommend three levels of priority: vital, discretionary, and convenience. Also, the backup requirement must be specified on a load-by-load basis. Generally, the vital loads may require 100% backup while the convenience loads may not require any backup at all. The discretionary loads may suggest varying levels of backup. The priority and backup information should be stored in the knowledge base along with the respective loads.

To illustrate, we have classified certain example loads into three levels:

Vital

Emergency lights
Communications equipment
Command posts

Discretionary

Operating rooms (duty cycle)
Air strips (duty cycle)
Mess halls
Recharging batteries

Convenience

Company areas
Street lights
Shower and sanitary facilities

Policies and procedures should then be implemented in code or using rules. This exercise is aimed at establishing standards which can be used for calculating and specifying power generation and distribution equipment.

Context-sensitive load prioritization. Scenarios exist where the same loads can be classified into different priority levels depending on the context.

Thus, priority of various loads may be a function of mission (or sub-mission). For example, the importance of certain loads depends on the nature of the mission - offensive, support, surveillance, etc. Another consideration is the interaction with other army units. For example, the medical facilities may be vital when a unit is playing a supporting role to units near the FEBA (Forward Edge of Battle Area) and discretionary when the unit is stand-alone. Load priority may also vary depending on the usage at that particular time. Communications equipment may require higher priority while transmitting important messages than when in receiving mode.

The extent to which such context-sensitive prioritization should be implemented is an issue to be further explored. Some of these priority levels are subjective and judgmental and some type of user override may be incorporated so that the user can change priorities if necessary. Due to this complexity some work in this area may be carried over to Stage II.

3.2.2 Definition and Representation of Constraints and Dependencies

Constraints are limits or restrictions that are placed on the value(s) of equipment or a group of equipment. Dependencies are relationships that describe how certain equipment value(s) are dependent on contextual information like the ambient temperature. Dependencies may also describe how certain pieces of equipment affect others.

Example constraints are a) maximum power supplied by a source, b) maximum inventory that can be carried by a unit, c) maximum distance that can be covered by a cable, etc. Constraints should be divided into "absolute constraints" and "situational

constraints." Absolute constraints do not change with the context. For example, the maximum distance that can be covered by a cable is a constraint that does not change with contextual information like the criticality of the mission. Situational constraints may be brought into effect depending on the nature of the mission, operational state of certain equipment, and temporal, environmental, safety or other considerations. They usually result from dependencies (as described in the previous paragraph). For example, the rated capacity of generators vary with the altitude. Situational constraints abound in a battlefield setting and the success of the system hinges on their specification, representation, and processing. Refer to Section 4.5.2 for information on the specific methods of constraint representation and processing as implemented in Phase I.

As mentioned before, dependency relationships exist between various pieces of equipment that directly affect their performance. For example, at any one time a particular source or one combination of sources provides power to an active load. The performance of the load is directly dependent on the output of that (those) power source(s). In LOADMAN, such dependencies are expressed using hierarchies. Named links are created between objects that are dependent and the expert system can use these links to identify the dependencies.

3.2.3 Equipment Specification

The project team along with Army personnel should survey typical applications for the average and peak power they use under various categories: vital, discretionary, and convenience. Refinement of such data should be carried out and various methods of estimation may be used for the three categories. For example, the amount of power used under the "vital" and "discretionary" categories may be conservatively estimated while the amount of "convenience" power is estimated more strictly. Also, the loads that prefer power from dedicated sources should be identified. This may be because the loads are particularly vulnerable to power fluctuations from other loads. The power required by the various load groups should be analyzed to decide the power ratings of the generators. The power required by the various loads should be analyzed to decide the capacity of outlets at the distribution boxes. The generation and distribution equipment should be designed with these requirements in mind providing for minor variations as necessary.

3.2.4 Inventory Planning Heuristics

Proper power distribution system management is possible only when the correct equipment is available at the site. This involves calculating the number and size of power sources, distribution equipment, and cables that would be necessary to support the mission.

Source heuristics. Various heuristics may come into play at this stage to decide whether and how to group the various loads. These heuristics will be incorporated as rules in the expert system and will be based on the policies and procedures to be established (see Section 3.2.1). Grouping may be necessary for various reasons:

1. Reduce the interaction between loads. For example, in one case the dentist's equipment imposed a greater load on the power source. This would cause the X-ray equipment to malfunction. There are three ways in which this situation can be tackled. One way is to ensure that both loads are not operated simultaneously. If this is not desirable/possible, we may consider planning for a power source that could support both loads without the interference (this may be overkill most of the time), or the loads could be powered by different sources.

2. Different backup requirements. For example, the critical loads of a camp like communication facilities would require a higher safety margin and hence a better backup facility. But other loads like the mess, company areas, etc., will not require the same level of backup.

3. Too much load for one power source.

Next, we suggest the calculation of "maximum simultaneous power required" in order to estimate the power required of each power source. This refers to the maximum power that would be required for each group at any particular time. Mainly, it takes into account the fact that some loads can not/will not be operated simultaneously. So it would be wasteful to provide for the sum of those (power) requirements. The calculation is done in two steps. Step 1 involves the calculation of power required by these "related loads." The allowable combination of states for each set of related loads are examined and the maximum power that would be required by each set is calculated. All these power requirements are summed to give the power requirements of related loads. Step 2 involves the addition of power requirements of independent loads (loads which are operable whatever the state of other loads). This measure ("maximum simultaneous power required") is used to calculate inventory requirements in terms of generators (actual and backup).

Layout Heuristics. After the power sources requirements have been calculated, the system will have to position these sources in the layout. After this, the connections are planned between the power sources and the loads. Once again heuristics in the form of rules will be used for this planning. Alternatively, the user could be requested to place the power sources and/or specify the connections.

Inventory/Supply Compilation. After the layout has been established, the system will be able to compile the inventory requirements in terms of generators, distribution boxes, switch boxes, cables, and loads.

3.2.5 Load Shedding Heuristics

Load shedding becomes necessary whenever more power is required by the various loads than is available at that time. This may be due to the failure of some power generation or distribution equipment, planned shutdown of sources, increase in the number of loads, or a combination of the above factors. The system must prioritize the various loads and cut out all the loads that are not absolutely necessary. Examples of such loads might be mess, company areas, and street lights.

The main goal in this situation is the maintenance of critical loads. Example of such loads are communication equipment, command posts, security points, medical facilities, landing zones, etc. A load shedding situation typically starts with a reduction in source capacity or an increase in load requirements.

Two methods of dealing with such a situation have been identified. One of them is a simple descheduling of already scheduled low priority loads to the point that the load requirements match the power available. This may not be always successful (as determined by some user-defined optimization tests). The second approach is to completely reschedule the loads based on priority. In Stage I, such advice will be offered to the user who will be responsible for switching the various loads as specified.

Upon partial power loss or knowledge about imminent power loss, the order in which the loads are brought down, and the degree to which they are brought down, can be crucial. With emergency power restoration the order in which the loads are brought up, degree to which they are brought up is also important (for example, the emergency generator may be overloaded by switching on all loads at once). However, these issues will not be addressed in Stage I which will be mainly geared towards the scheduling problem itself. Here "scheduling" is the process by which loads are selected to be turned on.

3.2.6 Load Balancing Heuristics

An example of this is the use of "turbine-gearbox combination." This piece of equipment is built to supply many loads with control over the power supplied to each load. Gears are used to vary the power that can be supplied to each load. It is thus possible to vary the power drawn by certain loads to accommodate other loads. This kind of power distribution is found in field hospitals and can be used to perform load balancing based on various factors. To perform the various calculations, it is necessary to convert the electrical loads to mechanical loads and then the gear ratios to support such a load.

3.2.7 Duty Cycle Scheduling Heuristics

The purpose of duty cycle scheduling is to minimize the overall load by meshing individual load requirements to achieve uniform loading. This would be a necessity under lower power availability conditions when it would be desirable to spread the load over time, and during fuel rationing conditions when it is necessary to operate all sources at maximum efficiency for minimum duration. It could also be used to reduce the logistics burden of carrying large power sources when smaller sources would be sufficient with proper load operation planning. Also, generators work best when they are working close to maximum load. Thus, planning for a uniform load close to the rated capacity of the generator(s) is a good idea. The duty cycle scheduling rules will have to accept inputs which specify the constraints (optimization criteria, max load, max time slot, loads to be scheduled, etc.). In Stage I, the duty cycle rules will advise the user against using combinations of loads that would make undesirable demands on the power sources.

3.3 STAGE II OBJECTIVES

Stage II would involve the development and implementation of an on-line system. This system will include expanded and enhanced knowledge to accommodate:

- Different kinds of missions
- Automated interface to the Power Distribution System
- Maintenance planning
- Training plan

Various scenarios and desirable system actions are described below to motivate identification of needs and finalizing the scope of the project.

a) Camp setting; all loads operational. Diesel generator fails dropping available power to 60% of that required. Other power sources may or may not be available. Situation requires addition of other sources and/or reduction/reconfiguration of loads. Simplest situation that must be handled.

b) Changing load requirements due to environmental conditions. There is a need to rebalance the loads. Again, this could be handled by reconfiguring power sources or loads.

c) Periodic loads. Dovetailing may be used to optimize the load with minimum power requirements. One example of this type of load would be the lighting for airstrips.

The paragraphs below describe applications areas that are being considered at this time for implementation in Stage II.

3.3.1 Autonomous Monitoring and Control

Autonomous, "intelligent," power distribution modules are the next step in improving the efficiency and execution of the load management system. These modules can be designed to respond to commands issued by the expert system. Closed-loop control can be used to enhance the reliability of the system. This is because in closed-loop systems, feedback is provided from the loads to the computer and this helps the computer verify that its commands are being carried out. However, the extra wiring and sensors that must be provided may make it prohibitively expensive and so the practicality of providing closed-loop control must be investigated.

Monitoring equipment (sensors/placement). Monitoring of generators and loads is a must if the expert system is to work autonomously. The expert system should be able to recognize generator failures so that it can bring alternate generators in to service. Recognizing load failures helps the expert system schedule other lower priority loads. The ability to recognize load failures and operation status is less important and so may be implemented on a limited basis. Sensors may be placed on the distribution equipment and on the loads for complete monitoring. On the other hand, sensors may be placed on the loads, and the topology of the system used to calculate the loading at the distribution. But the most cost-effective and perhaps the most realistic method is to place the sensors on the distribution boxes. This will not help the system locate which particular load failed, but would provide enough information to calculate power consumption and thus the availability of power so that the scheduling of other loads may be planned.

Controlling equipment. In addition to monitoring equipment, an autonomous system must have a method of controlling the equipment. It is desirable, both in terms of cost-effectiveness as well as maintenance and logistics, to use the power line to carry the control signals. One method (scheme) which has been successfully used in commercial home control systems works by transmitting a high frequency coded command sequence through the power lines. This command sequence is used to activate the individual switches at the various loads. The entire system consists of one command module and many receiver modules. The home system is described below, but it is expected that receiver modules capable of higher power output can be designed easily.

Command modules. The command modules are built using custom LSI (Large Scale Integration) ICs (Integrated Circuits). When fully expanded, the system can accommodate 256 independently addressable receivers. The function (on, off, lower, or increase power) and address codes are combined in the digital message sent by the command module. The transmitter in the command module generates 120-kHz signals that are used to modulate the AC line with pulse-width modulation. Each message is transmitted in true and inverted format on successive half cycles of the waveform. A complete message takes 183 ms to complete. Actual attachment to the AC line is accomplished by means of a transformer and

capacitor coupler. This isolates the transmitter from the power line ensuring safety without unduly increasing the cost.

The command module can also be used to intermittently restore the status of any module (every so many minutes). This is useful where a module may be turned off by a transient or non-system-generated command. Restore can also be carried out at the command of the expert system.

Receiver modules. Each receiver module incorporates a LSI IC and monitors the AC line, waiting for a coded message corresponding to its address. When it recognizes a message addressed to it, the wall-receptacle module energizes a relay. Modules can be built to use a triac instead and have the capacity to increase or decrease power to the load in response to control commands. Various modules are available to handle loads from lamps (lamp modules rated at 300W) to heavier, non-resistive appliances (contact-closure-output appliance modules rated at 1700W). The LOADMAN system must be able to accommodate heavier loads and it is expected that receiver modules capable of supplying the necessary power can be found, or existing modules can be redesigned easily.

Priority-encoded receivers. To reduce the burden on the expert system, the receiver modules could be prioritized by incorporating switches on them that select the level of priority. The expert system can then turn the power on or off for the various priority levels. This scheme could be implemented on a load-by-load basis (at higher cost) or on a feeder-by-feeder basis where each feeder cable could supply power at a particular level (and could be turned on or off). The computer system will use these levels to drop loads as the power generation or requirements change. Upon shortage of power, the convenience loads will be dropped first and then the discretionary loads if necessary. Prioritization of the receiver modules need not be rigid. Depending on the situation the priority may be changed. For example, the medical facilities may be moved from the discretionary level to the vital level if there are many critically ill personnel who needed immediate attention. This would involve just changing the switch position on the receiver module supplying the facility.

3.3.2 Health Monitoring of Power Equipment

Critical to power systems management and distribution planning is the maintenance of equipment (especially power generators). Some symptoms that may signal a problem are the overheating and overloading of generators. Some sensors are already available on the diesel generators and others can be added easily. However, such sensor information must be fed back to the expert system and this might pose a cost and logistics burden in terms of the wires and connections that would be necessary. Perhaps, the location of the expert systems computer close to the power sources could help alleviate the problem. Since the impact of such a health monitoring system could be considerable, investigation of the idea to determine its practicability is worthwhile.

3.3.3 Simulation and Training

Battalion Logistics Simulation and Training has been identified as key areas in which the LOADMAN expert system could be used. To provide for this capability, the system should operate in advisory mode. Explanation capabilities and the ability to read scenario information from diskettes and report the changes in the situation to the user should all be implemented to achieve this purpose. "What if" reasoning (a feature by which the expert system can work from a context modified by the user to produce solutions suitable to the new context) is an especially attractive facility that could be very valuable in training.

Since the representation of facts, knowledge, constraints, and rules in LOADMAN is natural, declarative, and object-oriented, the development of the above-mentioned simulation and training facility can be achieved easily.

3.3.4 Enhanced Schematic Displays

The camp layout has been identified as an important consideration in the processing of some constraints. Hence, it is important to display the campsite in as much detail as is possible. One of the methods of display that is being considered is to provide a graphic display of the location and icons made up of digitized pictures to represent the various equipment. The user can select and drag these icons to various positions on the screen to specify the layout. These icons will also be used to display information about the corresponding equipment, when selected.

The icons can also be used to facilitate user input. For example, they can be used to specify equipment that has failed or whose priority has changed. Also, the display system could provide for editing by allowing the user to connect and disconnect equipment. Parts in the inventory could be represented using digitized pictures to reduce the chances of an error. A "screen dump" of such a display to the printer will be of great help to the personnel who make the actual connections in the field. Digitized pictures of correct (and safe) connections at the generators/loads could be stored inside the computer and displayed or printed. This will reduce misconnections and damage to costly equipment.

The design of such a display system should be investigated. System portability considerations are bound to rule out some of the most popular high resolution systems. But a good compromise should be worth the effort made in this area.

SECTION 4

LOADMAN DEMONSTRATION PROTOTYPE

4.1 SYSTEM DESIGN CRITERIA

4.1.1 Nature of the Problem

The nature of the problem to be addressed by LOADMAN is one of constraint management and system optimization under those constraints. Example constraints are a) maximum power supplied by a source, b) maximum inventory that can be carried by a unit, c) maximum distance that can be covered by a cable, etc. Constraints can be divided into "absolute constraints" and "situational constraints." Absolute constraints do not change with the context. For example, the maximum distance that can be covered by a cable is a constraint that does not change with contextual information like the criticality of the mission. Situational constraints may be brought into effect depending on the nature of the mission, operational state of certain equipment, and temporal, environmental, safety, or other considerations. For example, the rated capacity of generators vary with the altitude. Situational constraints abound in a battlefield setting and the success of the system hinges on their specification, representation, and processing.

The prototype development began with a discussion of various power distribution and load management scenarios that the system would be expected to handle. A survey of technical papers was then performed to consider these scenarios against research already done in this area. Very little work in the area of generic scheduling systems that may be adapted to handle specific problems has been done. One reason for this is that the complexity of the problem quickly overwhelms the designer forcing customized solutions rather than generic ones. Nevertheless, the survey provided numerous pointers and suggested generic techniques for the design of an object-oriented, generic constraint representation and management system.

4.1.2 Development Strategy

The LOADMAN Demonstration Prototype was developed using rapid prototyping techniques focused on helping the developers assess the feasibility and importance of the features and functions of the expert system. Having a demonstration prototype serves a secondary purpose of improving communication of the concepts to others. The rapid prototyping environment creates an atmosphere where the consequence of failure is low, thus, enhancing

productivity and creativity. The development objectives of the LOADMAN demonstration prototype were, thus, directed towards testing particular methods, evaluating the feasibility of certain new approaches and features, and providing a realistic and interesting simulation of the full prototype for review by the Army personnel. These objectives influence the rapid prototyping guidelines by placing more emphasis on the development interface and proof-of-concept and less emphasis on performance and completeness.

Another important aspect of rapid prototyping is intelligently bounding the scope of the application. The LOADMAN Demonstration Prototype can be thought of as a scale model and is, thus, a partial implementation of the system. In order to achieve this, sacrifices were made in the areas of completeness, performance, functionality, and interfaces. The approach used to bound the Prototype provides the ability to establish a modular development process whereby, once the core functions are established, new functions can be themselves rapidly prototyped, and once operational, added to the core. In this manner, each dimension of the full prototype, which is sacrificed originally, can benefit from the usefulness of rapid prototyping as it is added. Thus, the demonstration prototype provides an experimentation test bed for developing the full prototype.

The strategy has been to keep the specific applications in mind while trying to formulate generic techniques. Design stages were followed with specific implementation stages to make sure that the final solution will be relevant and useful. Thus, the system has been designed to take into account various constraints and recommend equipment and their placement for successful load distribution. The role of the system will eventually span a wide area, operating under different modes like 1) recommendation of layout of power sources and distributors, 2) generation of inventory requirements, and 3) dynamic balancing of power sources and loads. The system could then be used for logistics support, monitoring, prediction, reconfiguration after a field casualty, and optimal matching of source and load requirements.

However, the role of the system as described above is too big to be handled in one step, preventing methodical design of lower level subsystems. In order for the project to be immediately useful, development of the demonstration prototype was made concentrating on areas that will demonstrate the methodology and feasibility of the project without requiring additional equipment or interface to the power generation and distribution system.

4.2 HARDWARE, SOFTWARE, AND INTERFACE

4.2.1 Hardware Selection

Since the logical conclusion of this project is to provide army units with this computer system (so that dynamically developing problems at the site can be handled), the hardware must be

inexpensive. Also, versions of the machine should be available that could be carried and used easily in the field. Thus, the project was developed on an AT-class Personal Computer which is the least expensive and portable machine that can support a LISP-based object-oriented delivery environment. A Color Graphics Adapter "text mode" screen is used for displaying the layout of the site because this offers maximum speed with minimum processing power. In this display mode, the screen is divided into 80 columns and 25 lines of character areas and only the ASCII characters and symbols can be displayed in each of these areas. The exact details of the Demonstration Prototype hardware are as follows:

IBM PC/AT or 100% compatible with
- MS-DOS 3.0 or higher
- Serial port
- Floppy drive
- Hard disk (10 M available room)
- Color Graphics Adapter and Monitor
- 5 MB Extended memory
- Three-button mouse

4.2.2 Software Selection

For the purposes of expert systems development, including rapid prototyping and testing, an entire development environment with debugging tools is a must. Thus, Golden Common LISP 286 developer package and KEYSTONE (a hybrid expert system development and delivery environment) were the software tools used. Decision on the software tools was based on the knowledge representation capabilities, sophisticated developer's interface, and low cost at the time of delivery. In addition to frame-based representation and rule processing, KEYSTONE provides a versatile windowing environment which provides the flexibility for trying out different screen configurations and display methods.

Once the interface design, knowledge representation, and processing have been finalized, a few advantages of the development environment could be given up for advantages in the form of cost, transportability, and more modest hardware requirements so that the delivery environment is viable.

4.2.3 System Interface

The LOADMAN system interface is an advanced and functional interface using windowing facilities and mouse and menu based selection and input. This is based on the windowing and menu facilities provided by KEYSTONE (the underlying hybrid development shell).

Apart from displaying a plan of the campsite, the interface helps the user create knowledge representations for a particular mission and associated equipment. Also, the interface allows the user to control the inventory of equipment used by a mission

using menu-based instance creation facilities. For example, the user can create a "TELEPHONE" instance using the Inventory menu and place it on the layout.

4.3 KNOWLEDGE REPRESENTATION AND REASONING METHODOLOGY

4.3.1 Object-oriented Domain Representation

Object-oriented programming is an expert systems engineering technique where system components and their inter-dependencies are represented using "software" objects and slots within the expert system. Object-oriented programming also makes use of code attached to objects to provide a highly modular and manageable implementation. This approach is well-suited for modeling inter-relationships between generators, loads, cables, etc.

Definition of the domain objects is carried out through a user-friendly interface which is designed such that the system curator need not have any special knowledge in the AI field. The knowledge required for this process consists of characteristics of the components and their relationship with other components. Typically, such information is well known by the curator or is available from specialists. This object-oriented approach to knowledge representation allows the knowledge base to be modified simply by adding (or removing) objects and readjusting the associated links between the new arrangement of constructs. The advantages of object-oriented programming follow:

Natural way of representing knowledge. The system is modeled to explicitly represent the function and relationships of individual system elements.

Adaptability. The knowledge base is inherently modular and does not rely upon compiled knowledge, i.e., knowledge gathered from previous specific scenarios and applications. This makes it easier to use the same knowledge base for different applications and hence adaptable.

Increased life cycle. The knowledge base can be modified and extended easily to reflect changes. Also, the knowledge base can be fine-tuned by refining the knowledge incrementally.

Verifiability. Explicit knowledge, that is found in object-oriented systems, is easier to verify because of the independent nature of each "chunk" of knowledge.

4.3.2 Reasoning Mechanisms

Rule-based Reasoning. The reasoning process in this system combines factual domain information with the heuristics of the human experts. Facts are independent pieces of information which are best represented declaratively. Constraints are facts that place a limitation on one or more domain objects. Heuristic

information, in the form of rules, use facts to generate "intermediate facts" or infer conclusions and solutions. They (the rules) are processed by an inference engine.

In this domain we envisage two sets of rules, 1) dependency rules for generating situational constraints from situational (contextual) data using dependency heuristics, and 2) planning rules for generating the schedule using the collection of absolute and situational constraints and factual domain knowledge. Figure 1 illustrates this concept graphically. These rules may be further subdivided into rule-classes according to their specific function. This structuring of rules improves the modularity of the system making it easier to design, maintain, and extend the system. In the demonstration prototype, rules are used in a limited manner, mainly to determine the violation of proximity constraints.

In developing the rule-bases one should recognize that rule testing may be repeated unnecessarily if the rules are not carefully programmed. Developing an efficient and consistent set of rules for a complicated domain can be expensive and time-consuming. This is where the above structuring of rules will help in focusing rule processing and improve the efficiency of rule processing.

Conventional Programming. Some procedural components of the solution process are handled using conventional programming in the form of LISP code.

4.4 SYSTEM IMPLEMENTATION

4.4.1 LOADMAN Knowledge Base

Since the LOADMAN system is object-oriented, all entities in the problem domain are represented using objects. Objects are logically grouped into "knowledge bases." This helps the expert system and the user locate and process the object easily. Objects may be organized into hierarchies which helps classify them into the various "types." For example, the "SOURCES" object represents the class of objects that are power sources, such as "diesel generators." Therefore, all power generator objects in the system would be below the SOURCES object (in the hierarchy). Graphically, a knowledge base is represented using the names of the various objects and lines between the names to specify the hierarchical relationships. Several hierarchical relationships may exist in one knowledge base and some hierarchies may extend into other knowledge bases. See Figure 2 for an illustration.

The LOADMAN expert system has a system knowledge base called "LOADMAN" that contains objects that store global information (information that is generally applicable within the domain). Thus, this knowledge base contains template objects representing most domain objects. These template objects have all the various slots that are necessary to fully describe the domain object, but

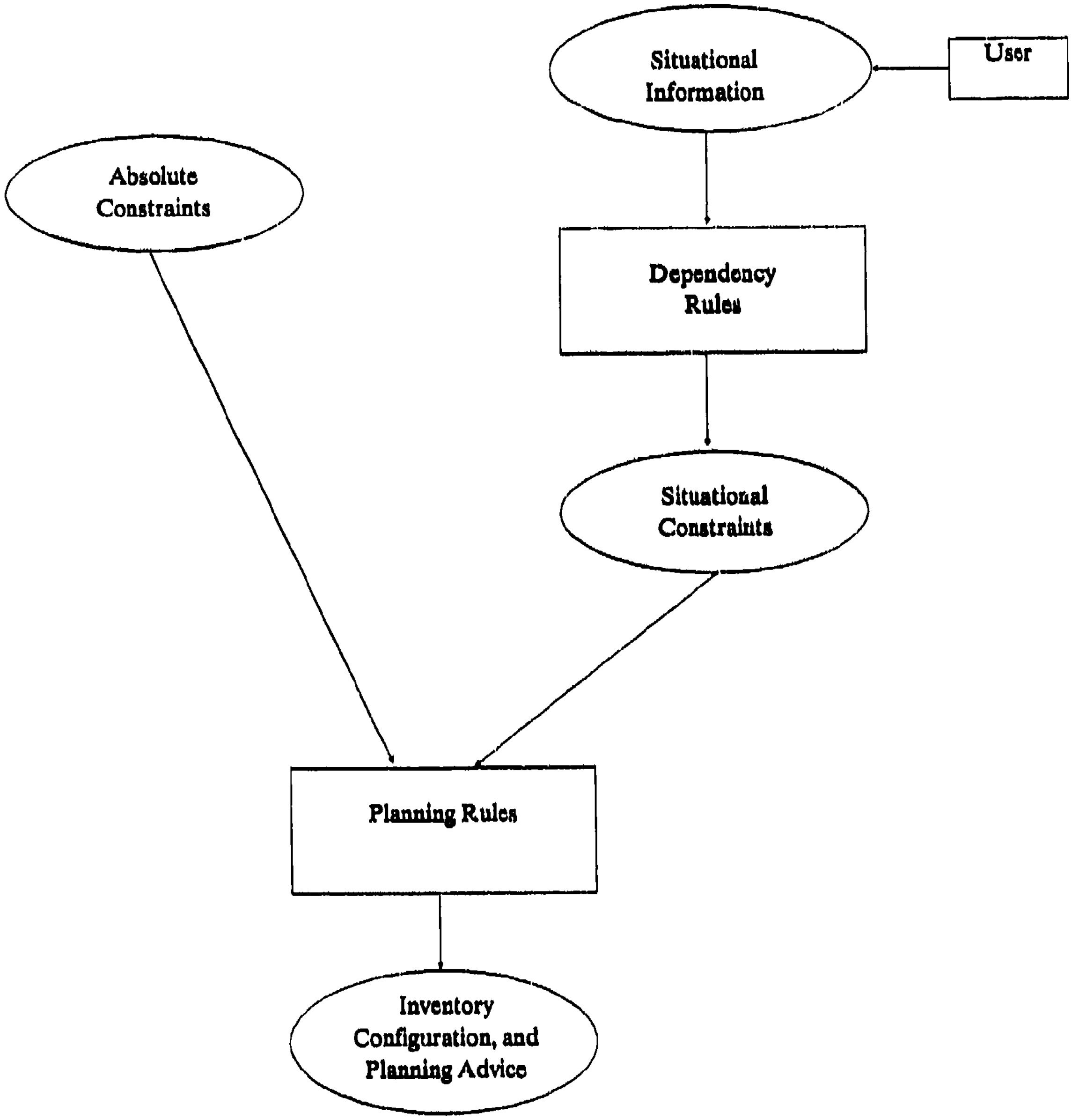

Figure 1. The Reasoning Process

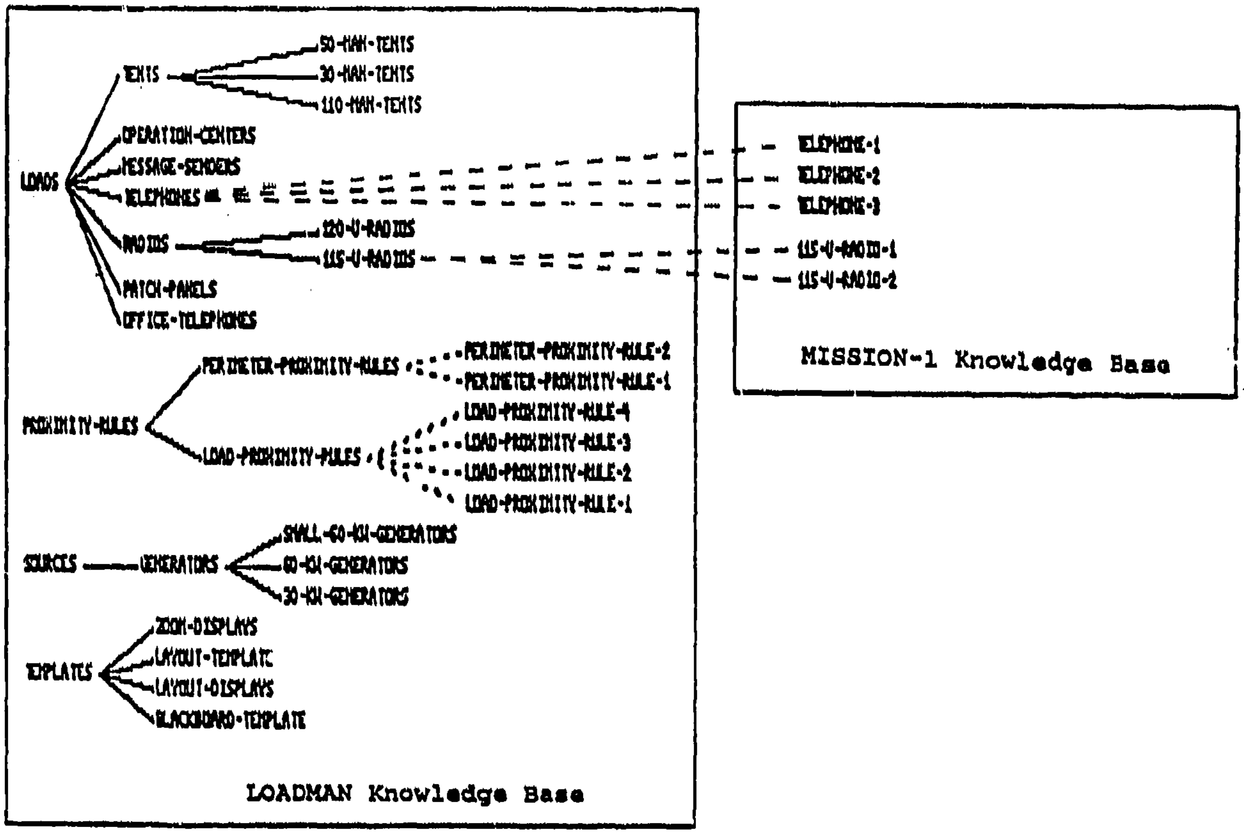

Figure 2. LOADMAN Knowledge Base Structure

with none of the specific information filled in. In other words, they are prototypical software objects that describe every item that could be part of a mission (generators, radios, tents, telephones, etc.). Examples of such objects are 30-KW-GENERATOR, 60-KW-GENERATOR, 120-V-RADIOS, etc. The slots, along with default values, will be inherited by specific instances when they are created in various missions. The LOADMAN knowledge base is one of the knowledge bases shown in Figure 2.

4.4.2 Mission Representation and Handling

The previous section described the system knowledge base, "LOADMAN." Other knowledge bases are created as missions are loaded into the system or created afresh. LOADMAN has been designed to model missions independently. Each mission will be given a mission name by the user and this will be used to create a knowledge base and store mission-specific information. The details of the mission can be entered by the user and saved for future reference. The mission knowledge base stores different kinds of information like the camp size, altitude, and the nature of the mission in a structured manner. It also stores information like the location of a particular load, power requirements of loads, and their role (main, backup).

The Blackboard Object. An object of central importance in each mission knowledge base is the Blackboard. This stores general information that does not correspond to any one object that is part of the mission. For example, the number representing the number of instances of a particular type of object and the maximum number of such instances allowed are specific to one particular mission but not to a particular instance. So, slots named after the type objects are created in the Blackboard object and used to store the maximum number and the current count of the instances.

Other important slots in this object are:

PROXIMITY-CONSTRAINT - This stores the proximity constraints that are specific to a mission.

CAMP-SIZE - This stores the camp size in feet (e.g., Height: 200, Width: 550)

DISPLAY-GRAPH - The value of this slot specifies what value to display on the "Overall power status" graph. For example, if the value is SHOW-USED then the graph represents power that is used up by loads that are already scheduled against time.

MISSION-START - The value of this slot represents a reference number that indicates the start time of the mission. This is usually 0.

MISSION-END - The value of this slot represents a number that indicates the end time of the mission. It is an integer that represents the number of minutes.

POWER-AVAILABLE - This slot stores the power availability pattern. It is a list of lists with each sublist representing a change in the amount of power available. The first item in the sublists is an integer which represents the time of the power change relative to the start of the mission. The second item in each sublist represents the new power (in watts).

VIOLATIONS - This slot holds details of any violation of constraints.

WARNING-FLAG - Flag that is set when constraint warnings are encountered.

4.4.3 Inventory Representation and Handling

Each piece of equipment in the mission is represented by an object in the mission knowledge base. This object will be an instance of a "type" object in the LOADMAN knowledge base and, thus, will inherit all its functional characteristics from the "type" object. Equipment "types" can be accessed through the Inventory menu and instances created as necessary. Each such instance will also be a member child of the LAYOUT object.

The system automatically generates names for these objects by concatenating a number (which is incremented every time an object of a particular type is created) to the "type" object name. For example, when the fifth instance of 115-V-RADIO is created, it will be named 115-V-RADIO-5. When an instance is created, the user is asked to place the object on the layout. This location is stored on the object and used to position the object in the Layout and Zoom windows.

Example Load Instance. 115-V-RADIO-3 is an instance of 115-V-RADIO and has the following slots:

ASSOCIATED-OBJECTS - This slot stores objects whose use is in some way related to this instance. In other words, this slot represents other objects in the mission that have common simultaneous constraints with this object.

CAN-CONTAIN-ITEMS - This is a flag which indicates whether a particular load instance can include other load instances. For example, a TENT (which is itself a load) can contain other loads like TELEPHONES, etc.

INSTANCE-OF - This stores the name of the "type" object. For example, the value here is 115-V-RADIO.

SYMBOL - Stores an ASCII symbol that is used to represent the object in the layout. Here, the symbol value is 'R.'

VOLTS - Stores the voltage required by this load (e.g., 115).

LOCATION - Stores the location of the object on the layout.

PART-NUMBER - Stores the Army part number for this object. Here, it would be AN/TRC-110.

POWER - Stores the power required by this load (in Watts) for the various operating states. For example, "OFF: 0 RECEIVING: 1000 TRANSMITTING: 4318" represents the power required by 115-V-RADIO-3.

POWER-FROM - Slot stores the source from which this load receives power (e.g., 60-KW-GENERATOR-1).

PRIORITY - Stores a number between 1 and 9 as the priority of the load. Lower numbers denote lower priority.

POWER-NEEDED - Stores the on and off times that is planned for this load.

Example Source Instance. 60-KW-GENERATOR-1 is an instance of 60-KW-GENERATOR and has the following slots:

CONSUMPTION - Slot stores the rate of fuel consumption, in gallons per hour. Here the value is 6 gal/hr.

FUEL-CAPACITY - Specifies the maximum amount of fuel that can be stored in the generator.

LOCATION - Stores the location of the object on the layout.

PART-NUMBER - Stores the Army part number for this object. Here, it would be PU/700.

POWER - Stores the rated power output (in watts) of this source (e.g., 60000).

POWER-TO - Stores all load objects that this source provides power to (e.g., 115-V-RADIO-3, TELEPHONE-1, etc.).

SYMBOL - Stores an ASCII symbol that is used to represent the object in the layout. Here, the symbol value is 'G.'

VOLTS - Stores the voltage at which this source provides power (e.g., 416 V).

Other slots in the source instance object store methods to create, delete, create-name, draw, undraw, display, etc. The LOADMAN system supplies standard methods to achieve all this, but the user is free to modify or introduce different procedures.

4.4.4 Layout Representation

Representation and display of the campsite is an important feature of the LOADMAN system. This is because equipment positioning and interconnection plays a significant role in load management planning and inventory planning. The objects that are

used to represent such information are described below. These objects are created for every mission.

The Layout Object. The object that ties together all domain instances is the LAYOUT object. This object has slots that specify various parameters used for representing a campsite on the display. Also, all equipment instances (loads, sources, distributors, etc.) which are part of the mission are child objects of the Layout object.

The Layout object has the following slots:

LAYOUT-X-SCALE - This slot stores the scaling factor that is used when the campsite is displayed on the screen. In other words, it is the number of feet that each character cell on the screen represents - in the X direction (e.g., 10 feet/cell).

LAYOUT-Y-SCALE - This is the scaling factor that is used in the Y direction (e.g., 15 feet/cell).

MULTI-ITEM-SYMBOL - This specifies the symbol that is used to represent multiple items that fall in the same cell in either the Layout or the Zoom window.

POSITIONS - This stores all instance objects that are currently displayed in the LAYOUT window and their screen positions (relative to The LAYOUT window's origin).

ZOOM-POSITIONS - This stores instance objects that are currently displayed in the ZOOM window and their screen positions (relative to the ZOOM window's origin).

ZOOM-X-SCALE - This slot stores the scaling factor that is used for the Zoom window, in the X direction (e.g., 5 feet/cell).

ZOOM-Y-SCALE - This slot stores the scaling factor that is used for the Zoom window, in the Y direction (e.g., 5 feet/cell).

Layout-panel object. The slots in this object store window-specific information about the Layout display. The various slots in the object describe the window's color, border width, methods for window operations (such as create, delete, open close, etc.), title, region, and the windows used as X and Y pan bars.

Zoom-panel object. The slots in this object store window-specific information about the Zoom display. The various slots in the object describe the window's color, border width, methods for window operations (such as create, delete, open close, etc.), title, and region. The CELL-LOCATION slot stores the location of the ZOOM area on the Layout window (in screen coordinates).

4.5 SYSTEM UTILIZATION

The LOADMAN system is window and menu based and is easy to use for the most part. Routines that prompt the user to add or delete information to/from the knowledge bases have been created. These will insulate the user from the software details through the use of menus and specific questions about the item being updated. Important system functions can be invoked using the main menu which can be accessed from the LOADMAN icon. The main menu can be accessed by placing the mouse cursor on the LOADMAN icon and pressing the left button. A selection can be made by moving the mouse cursor to a particular choice and releasing the button. The LOADMAN icon and main menu are shown in Figure 3.

As mentioned earlier (Section 1.3), development of the demonstration prototype was suspended due to gaps in domain knowledge which made it very difficult to proceed with the completion of the prototype. The efforts were redirected into establishing the general philosophy and the methods to be followed in implementing a system of this nature. Parts of the prototype which were implemented up to that point are described here to demonstrate that advanced (knowledge based) computer techniques could be used to solve load management problems.

4.5.1 Campsite Displays and Inventory Menu

Two windows on the computer display will be used to display the camp layout at any time. One of these will display a major portion of the camp at low resolution and the other one will be used to zoom into a specific area of the camp. They are called the LAYOUT and ZOOM windows respectively. These are shown in Figure 4. The campsite layout display can be scrolled up and down or panned left to right to examine the entire campsite. The LAYOUT and ZOOM windows have been designed and implemented to help the user accurately position the loads on the layout. The LAYOUT object stores the scaling factor of the LAYOUT window and the ZOOM window, as well as the screen positions of each object drawn in the LAYOUT and ZOOM windows.

The Inventory menu (see Figure 4) and the LAYOUT and ZOOM windows are very functional. For example, all symbols on the LAYOUT and ZOOM windows represent object instances and are mouse-sensitive. Information about these instances can be obtained by placing the mouse cursor on these symbols and clicking the buttons. Also, instances may be deleted or their software object displayed etc. More specific information on all these can be found in Appendix A, "Tutorial/Demonstration Sheet."

<u>LAYOUT Window</u>. The LAYOUT window is designed to show a major portion of the camp with very low resolution. It is also designed so that it can be used to pan around the entire camp. The resolution of the LAYOUT window can be modified by the user. The user can mouse on any item in the LAYOUT window and bring up, among other things, an explanation of the item. This gives some key information regarding the item. Likewise, the user can also,

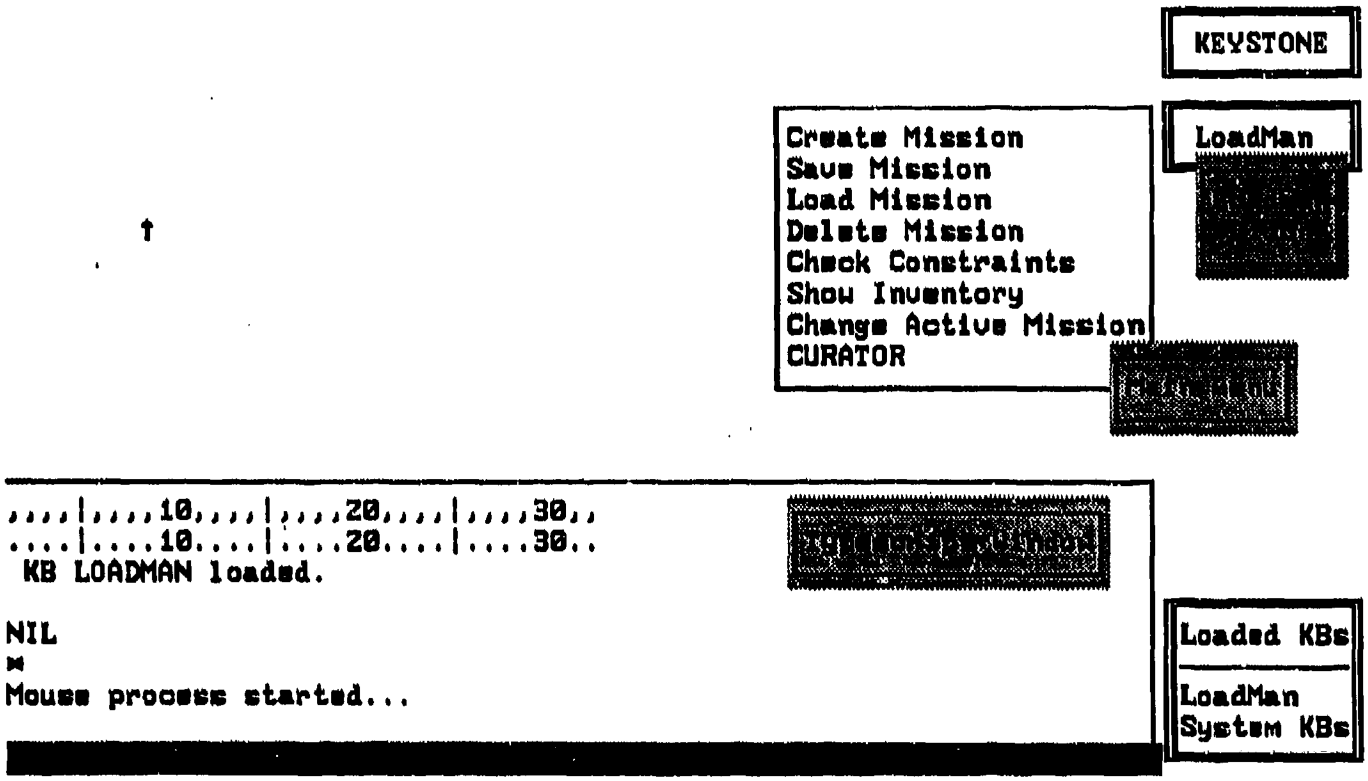

Figure 3. LOADMAN Icon and Main Menu

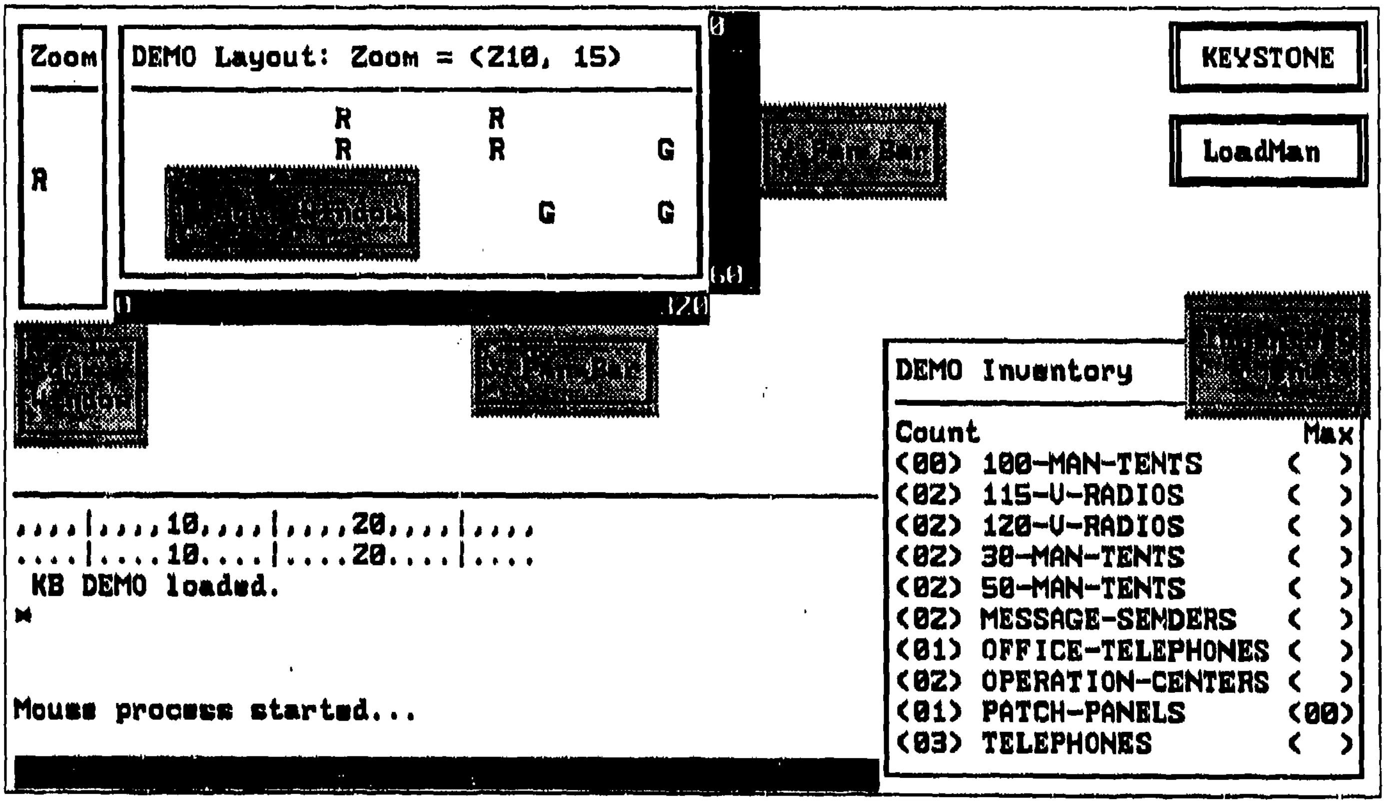

Figure 4. The Layout Window, Zoom Window, and Inventory Menu

delete the item, move it to a different location, or display the software object that describes the item.

ZOOM Window. The ZOOM window is designed to show a small portion of the camp at a higher resolution than the LAYOUT window. It can be moved around and positioned on a small part of the LAYOUT window (using the mouse). This allows the user to position the equipment with greater accuracy by first moving the ZOOM window to the general area and then indicating the specific position of the equipment in the ZOOM window.

Menus. A major portion of the demonstration prototype is menu-driven. This makes it very easy for the novice to learn to use the system. When the LOADMAN environment is initialized, a LOADMAN text-icon is created. The Main Menu can be accessed from this icon (Figure 3). This menu has options to Create Mission, Delete Mission, Change the current mission, and Show Inventory menu for the current mission. In addition this menu has a Curator option which allows the user to modify load and sources information, and constraints. Figure 5 shows the curator menu selections. All major mission manipulation functions can be accessed through this menu.

The Inventory menu shows the current count and maximums for each system known to the system. The description of the items can be either the part number or a "pseudo-name" describing what the item is. For example, telephones can be either "AN/TCC-73V2" or "TELEPHONES." Each item can be selected using the mouse to bring up a menu of actions that can be performed in that item class. These actions are:

ADD: Creates a new item instance, asking the user to position the item in the Layout/Zoom windows, checking to be sure the maximum has not been exceeded.

DELETE: Prompts the user with a menu of all known instances of the item type. If the user chooses one, it is deleted.

DISPLAY: Displays the selected item's "type object" in a window.

MAXIMUM: Allows the user to enter the maximum number of this item type allowed in the camp. If the number is less than the number currently positioned, the change will not be made. Using this feature, the user can guard against inadvertently using more equipment than is available.

4.5.2 Specification and Processing of Constraints

Proximity constraints. Proximity constraints allow the user to specify spatial constraints on the location of certain objects with respect to other objects. In other words, proximity constraints specify that particular load instances or all instances of a particular load class cannot be closer or must be closer than a specified distance from another instance (or class

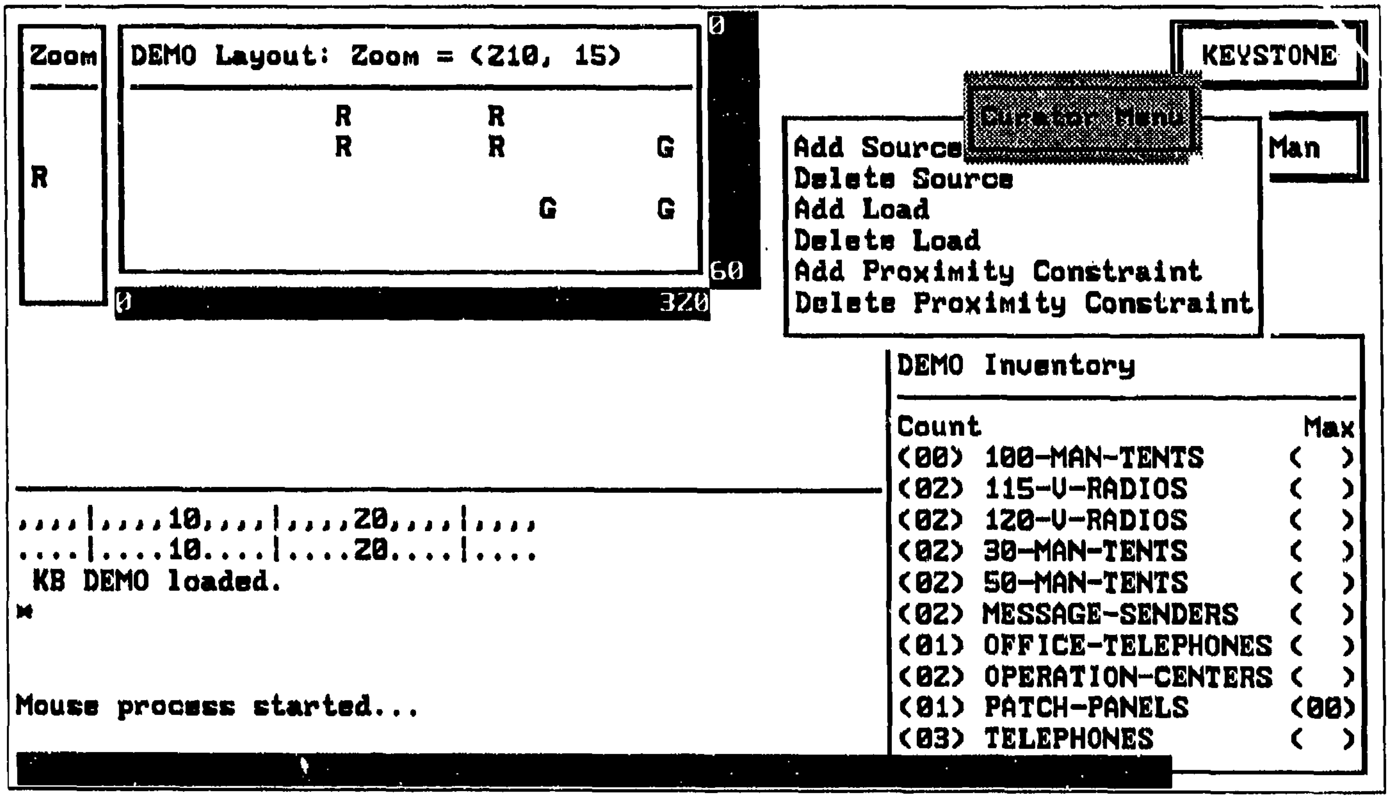

Figure 5. The Curator Menu

of instances). For example, RADIOS must be closer than 20 feet from ANTENNA-1. Also, the perimeter of the camp can be a constraint (e.g., RADIO-1 must be further than 50 feet from the camp perimeter). The proximity constraints are divided into two types: load proximity and perimeter proximity. These enforce, respectively, load class/instance to load class/instance distance and load class/instance to camp perimeter distance conditions. Proximity constraints can be modified by using the "Curator" selection on the Main menu. A set of rules and associated support functions were created using KEYSTONE's inference mechanism and the LISP language, which allows both pattern matching and LISP function calls to enable the expert system interpret the constraints. Some interface routines have been written to allow the user to specify such constraints without any programming knowledge.

Proximity constraints are used in Load Positioning (where the system automatically decides where various loads should be placed at the campsite) and Distribution Networking (where the system decides where the distribution boxes should be placed amongst the different loads and how the entire system should be connected). See Section 4.5.4 for an outline. At this time, each load item is checked against the list of constraints. If it has a constraint (either specifically that instance (e.g., RADIO-1) or its class (e.g., RADIOS), its distance to the closest camp boundary is computed and compared to the constraint (either for too low a distance or too high a distance). If a violation occurs, the instance and the constraint are stored on the mission blackboard for either perusal or later processing. A message is also displayed on the screen. For load proximity constraints, the process is the same, except the load must be compared to all load instances specified in the other half of the constraint; for example, "RADIO-1 must be closer than 10 feet to ANTENNA-1." In this example, the RADIO-1 instance would be compared to the ANTENNA-1 instance, their distance computed, and the distance compared to the constraint.

<u>Simultaneous Constraints</u>. Simultaneous constraints are limitations/relationships that exist between loads such that certain operational states are not simultaneously attainable or are avoided by the operators. In other words, these constraints represent load-state combinations that the expert system need not provide for when planning power sources. For example, in a radio-antenna combination, the antenna is not moved while the radio is transmitting. Since both these functions (transmitting and moving (tracking)) are costly in terms of power, the constraint information that both of these cannot happen simultaneously is useful for estimating the amount of power that should be planned for these two loads.

In processing simultaneous constraints, the system calculates the power that is used by related loads (in the example: the radio and the antenna) in the various legal (allowed) operational state combinations. The maximum power that is possible in any legal load-state combination is taken as the amount of power to be

reserved for these loads. See Table 4-1 for an example calculation. Here 750W, corresponding to radio TRANSMITTING and antenna ON, is the maximum power that can be taken up by the RADIO-ANTENNA load combination and so the expert system will plan to provide 750W for these two loads.

Table 4-1

Load-Instance/Operational-State Combinations for Antenna-1 and 115V-RADIO-1

115V-RADIO-1 (OPERATIONAL STATES) \ ANTENNA-1 (OPERATIONAL-STATES)	OFF (0W)	ON (50W)	ROTATING (500W)
RECEIVING (100W)	100	150	600W
TRANSMITTING (700W)	700	750	NOT LEGAL

4.5.3 Primary and Alternate Power Requirements

The first step in estimating the primary and alternate power requirements of a mission or campsite is the estimation of overall primary power under all allowable load/state combinations. The overall power required by a mission/camp depends not only on the loads that are part of a mission, but the various operational states that the loads may assume in relationship to one another. Such relationships help in estimating the power requirements closely so that the smallest power generation equipment that will do the job can be transported and used. This is important in terms of efficiency because generators operating close to full load are the most efficient, and also in terms of logistics where it is preferable to transport a smaller generator if it is sufficient to fulfill the needs.

"Simultaneous constraints" are used to specify the relationships described above and their specification and processing in Section 4.5.2. The use of simultaneous constraints in LOADMAN is menu-based and straightforward. The user selects the load-instance/operational-state combinations which are not "simultaneously allowed," using various menus presented by the system. This process is described below.

Adding Simultaneous Constraints. It is assumed here that the "type" object of the load instance describes the various operational states that the object can assume and the corresponding power levels. If this is not the case, the user should use the "ADD STATE" selection from the menu which can be accessed by clicking the left button on the instance symbol (e.g., "R" for 115V-RADIO-1) in the LAYOUT window, and selecting "SIMULTANEOUS." The system then prompts the user to enter the name of the (new) state to be added (e.g., RECEIVING) and then the power required by that instance while operating in that state (e.g., 100 (w)). These prompts are repeated and the user can add more than one new state and their corresponding power. Typing "Enter" terminates this process of describing the states. The operational states can be specified at the "type" object level (e.g., 115V-RADIO). To do this, one should start from the inventory menu (where the various type objects are displayed) and proceed as described above.

To specify that load-instance 115V-RADIO-1 should not be transmitting when its antenna ANTENNA-1 is tracking, the following procedure is followed. Clicking the left button on the instance symbol (displayed in the LAYOUT window) and selecting "SIMULTANEOUS" allows the user to access the "Add Simultaneous Constraint" selection. The user is then presented with a menu of legal operational states that has been specified for this load instance (see previous paragraph on how to do this). In this case, these are OFF, TRANSMITTING, and RECEIVING. The system then prompts for the other load instance and the user types in the name (ANTENNA-1). Then, the system presents the user with all the operational states that have been specified for this other load instance (e.g., OFF, IDLE, TRACKING). The user can then select "TRACKING" to complete the addition of the simultaneous constraint.

Deleting Simultaneous Constraints. Deleting a simultaneous constraint is performed by clicking the left button on a load instance symbol (e.g., "R" for 115V-RADIO-1) that is involved in the constraint, selecting "SIMULTANEOUS" and then selecting "Delete Simultaneous Constraint." The user is then presented with a menu of operational states that have been described for this instance. Once the state (involved in the constraint to be deleted) is selected, all the constraints associated with that state are displayed as a menu. The user can select the constraint to be deleted.

Primary power requirements calculation. Calc-max-simultaneous-power is the function that performs the estimation of the maximum simultaneous power required. When called with the name of the mission knowledge base, it returns the maximum power (in Watts) that should be allowed to meet the power requirements of all loads in the mission. It begins by grouping all loads related by a particular simultaneous constraint together and computes the maximum power that would be required by each group under all allowed combinations of loads/states. All group requirements are then totaled giving the overall power requirement.

4.5.4 Load Positioning and Distribution Networking

The placement of loads and distribution boxes and their interconnection using cables is also another area that is considered for automation by the LOADMAN system. Heuristics on load placement like "It is weight and cost efficient to locate heavy power consumers (loads) close to the power sources, thereby reducing or eliminating the need for feeder systems and additional cabling," would be used to solve this problem. Clustering techniques which scan the layout (once the loads have been placed) to determine load concentration areas, can be used to determine the placement of distribution boxes so that minimum cabling would be used for maximum coverage with minimum power loss in the cables.

During load positioning and networking, the proximity constraints are also considered because they specify spatial conditions that should be observed, like "MESSAGE-SENDERS should not be located closer than 20 ft. to the perimeter of the camp."

Use of Proximity Constraints

Load clustering. Scan-layout is a routine which has been written to cluster loads that have been placed on the campsite. It examines the campsite in strip-like sections (using a step-size supplied by the user). It scans two adjacent strips at a time making sure that load instances in an adjacent strip (but close enough) are not ignored during the clustering process. This routine is called by supplying a horizontal step-size and a vertical step-size which are judiciously selected based on the amount of standard cabling that is available. For example, if the desired cable length from distributors to loads is 50 ft., then the length along a diagonal would have to be 50 ft. So the length (and breadth) of reach that could be attained by a single distributor is (50 ÷ 1.414). Since a distributor could be placed in the center of all the loads, the cluster size could be twice the length/breadth reach (2 x (50 ÷ 1.414)) which is approx. 70.7 ft. So a convenient step-size would be 70 ft. (rounding from 70.7 ft.). This allows the scan-layout routine to divide the campsite in 70 ft. x 70 ft. sections and identify the clusters that fall into such sections. The scan-layout routine returns the cluster information as a list of lists. For example,

```
((TENT-1)
 (OPERATION-CENTER-1 TENT-2 TENT-3)
 (115V-RADIO-1 115V-RADIO-2)
 .
 .
 etc.
)
```

would mean that TENT-1 is all by itself. OPERATION-CENTER-1, TENT-2, and TENT-3 form another cluster, while 115V-RADIO-1 and 115V-RADIO-2 form a third cluster.

Use of proximity constraints. As mentioned before (Section 4.5.2), proximity constraints specify conditions on the placement of load instances. The user interface for specifying such constraints is through the "CURATOR" selection on the main menu. One of the selections in the CURATOR menu (Figure 5) is "Add Proximity Constraint." When this is selected, the user is presented a menu with the choices: PERIMETER (for constraints involving the perimeter of the campsite) and LOAD (for constraints involving other load instances). When "PERIMETER" is selected, the user is presented with a menu of "type" objects (e.g., OFFICE-TELEPHONE, MESSAGE-SENDERS, etc.). MESSAGE-SENDERS is selected to add a constraint involving message-senders. Next, the user is presented with a menu having the following selections: THISOBJECT, CHILDREN, PARENTS. The user can select THISOBJECT if the constraint is to be applied across all instances. For example, if all message-senders should not be placed closer than 25 ft. to the perimeter, then THISOBJECT should be selected. On the other hand, if the constraint applies to only one message-sender (say MESSAGE-SENDER-1), then "CHILDREN" should be selected to display all the instances (in the form of a menu). Now MESSAGE-SENDER-1 can be selected as the only instance object for which the constraint is valid.

Now the user is asked to enter the operator that is to be applied: < (less than) or > (greater than). To specify that the MESSAGE-SENDER cannot be closer than 25 ft., the user should type < (less than). Next the system prompts for the distance which is 25.

The constraint has been specified and can be used by the system while performing the placement. From the CURATOR menu, "Delete Proximity Constraints" can be selected for deleting any previously specified proximity constraint. As before, the specific constraint type is selected (LOAD or PERIMETER) and then the particular object is located (from the type objects and THISOBJECT/CHILDREN/PARENTS menu). Once the particular object has been identified, all proximity constraints of the selected type are displayed in the form of a menu. The user may select the constraint to be deleted.

4.5.5 Load Scheduling

This feature of LOADMAN is expected to change, and hence it is not fully implemented in terms of the user interface aspects. The basic idea of load scheduling is that the user should be able to specify continuous and periodic loads that could be allotted specific time slots by the expert system. Thus, the user would specify that a particular load needed "5509 watts every hour for half-an-hour throughout the entire mission."

During discussions with contact personnel at Ft. Belvoir, it became obvious that the ability to represent and use periodic load specifications was not necessary as most loads were continuous or "on-demand." Hence, the emphasis was shifted to areas other than load scheduling. However, step 7 and 8 in the

Demonstration/Tutorial Sheet (Appendix A) explains the procedure in detail. In short, planning of load schedules is done algorithmically by matching power availability and power requirement patterns. Options are generated for each load, ranked, and the best option is selected.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

Computer assistance in the areas of power generation and distribution planning, and load management is a necessary element of achieving increased mission efficiency and reliability and reduced risk to personnel. The recommended way to achieve such computerization is by the use of an expert system designed so that it operates well under normal as well as adverse conditions. Under adverse conditions it should be able to maintain a level of performance that is as good as the operating conditions will allow. In such situations the system may have to drop some loads or operate other loads at reduced power. Since these decisions could have major ramifications on mission success, the system will have to be designed according to well-defined Army policies and procedures.

5.1 CONCLUSIONS

TAI has investigated the feasibility of applying expert systems technology to generator-based power systems management. Based on its initial research effort in this area, the project team found that the use of such technology is indeed feasible and that its potential benefits are considerable.

Some conclusions from Phase I are:

1. Some kind of action is necessary to keep the power generation and distribution systems operating efficiently, reliably, cost effectively, and safely and to reduce damage to equipment.

2. Expert systems technology is appropriate for building a computer-based planning and control system to achieve the above purpose. The flexibility of expert system techniques in handling variations of a problem (different types of missions, failure scenarios, etc.) is a definite advantage.

3. Object-oriented programming techniques (a part of expert systems technology) enhance the flexibility, extend-ibility, and maintainability of the system.

4. Heuristics specific to a particular mission are easily included.

5. The proposed technology and methods promote modular system development and incremental development/implementation.

5.2 RECOMMENDATIONS

Arriving at the above-mentioned conclusions, the project team worked on the conceptual design of Phase II activities. Section 3 of this report incorporates the results of this effort. The project team also formulated the following recommendations:

1. Plans for Phase II development are discussed and the expectations are realistic. The final system will be beneficial to Army units in many ways.

2. However, a number of steps described in the report (see Section 2, "Domain Analysis and Findings") must be taken to successfully develop and deploy the envisioned system.

   - A body of knowledge should be formed that is derived from the theory of power generation and distribution systems. This is necessary because the current domain does not have an expert who is substantially better at solving the problem(s) (as gathered from Army comments and reports).

   - Standard practices, in the areas of load shedding and load scheduling, should be established which could then be followed and monitored to ensure the safe and reliable operation of power distribution systems. This is important because it is impossible to design a decision-making system without a definite idea of what decisions are desirable under specific circumstances.

   - Development of the LOADMAN expert system should be performed in two stages - planning (off-line), and monitoring and control (on-line).

3. Stage I should concentrate on specifying equipment, establishing policies and procedures for backup equipment, and establishing priorities for the various loads. Then the system should be built to plan inventory requirements, configure the equipment, perform load shedding when necessary, and perform duty cycle scheduling for heavy periodic loads. Thus, Stage I would result in an off-line advisory system that will be very useful in its own right.

4. Stage II should extend the system built in Stage I to produce an on-line, autonomous system that performs system monitoring, load management, and control. New hardware in the form of sensors and control circuits would be required at this stage to make the expert system as autonomous as is practical.

The LOADMAN project offers a significant opportunity to successfully implement an on-line expert system that can handle power generation and distribution problems. While further resolution of many questions is required, the completed work in Phase I clearly demonstrates that additional work in this area is highly desirable and would provide major benefits.

APPENDIX A

LOADMAN Demonstration/Tutorial Sheet

1. Load KEYSTONE as normal

2. Load LoadMan:

   2.1 (CD "C:\\LOADMAN") * or "P:" if on network

   2.2 (LOAD 'LOADLM)

   2.3 (LOAD-LOADMAN)

3. Load mission DEMO:

   3.1 Start mouse if not already started (press <F1>)

   3.2 Left-button on LoadMan window

   3.3 Choose "Load Mission"

   3.4 Choose "DEMO" from list of missions

4. After loading, explain screen:

   4.1 LoadMan Window -- upper right corner of screen
   Left-button on this window to show Main options.

Create Mission	;Creates new mission
Delete Mission	;Clears mission from memory
Load Mission	;Loads mission from disk
Save Mission	;Saves mission to disk
Show Inventory	;Displays the Inventory Menu
Change Active Mission	;Changes the currently active mission (for multiple missions in memory simultaneously)

   4.2 Typescript Window -- Blue 4- or 5-line window:
   User entry, error messages.

   4.3 Prompt Window -- Grey 1-line window at bottom:
   Prompts for user entry, explanation of processing

5. Explain mission screen:

5.1 Layout Window: Shows coarse view of camp layout, and component interaction. Grey pan bars show X & Y limits of screen in feet.

5.2 Zoom Window: Shows detailed view, with limited component interaction. "Zoomed" location (in feet) is shown in title of Layout Window. The actual area is highlighted in the Layout Window.

5.3 Inventory Menu (may have to left button on the LOADMAN icon to show) shows all known mission component types, the current count used in this mission, and the specified maximum number which can be used in this mission.

6. Exercise system:

6.1 Layout Window:

6.1a Item Explanation

Single item:

Left button on a G to display explanation about the Generator in a temporary window. Click anywhere to make it go away.

Overlapping items:

A "+" indicates overlapping items or items that are so close that they cannot be displayed separately with the resolution of the particular screen.

Left button on a "+" to display a list of overlapping items. Choose one for explanation. Click anywhere to make it go away.

6.1b Moving the Zoom Window

Right-button inside Layout window and the Zoom window will move to that location. Any items inside the region will be displayed in the Zoom window.

6.1c Scrolling Layout Window

WILL NOT SCROLL OFF OF CAMP.
So layout may not react when you are on an edge
Right button on left border. ;Scroll South
Left button on left border. ;Scroll North

Right button on bottom border. ;Scroll East
Left button on bottom border. ;Scroll West

6.2 Zoom Window:

6.2a Item Explanation

Left-button to explain item (single/overlapping items). Same as in Layout window.

6.2b Moving the zoom window in the layout window
Left button on left border. ;Move North
Right button on left border. ;Move South

Left button on bottom border. ;Move West
Right button on bottom border. ;Move East

6.3 Inventory Menu:

6.3a Add an item
Left button on an item type (TELEPHONES)
Click on ADD when the menu appears.
Position item in the layout window by clicking left button at desired location.
Position item in the zoom window by clicking at desired location.

6.3b Delete an item
Left button on an item type (TELEPHONES)
Choose DELETE when the menu appears.
Choose specific instance (highest numbered instance - the one you just added).

6.3c Move item to a different location
- doesn't work yet

6.3d Zoom
- doesn't work yet

6.3e Delete
- doesn't work yet

6.3f Display a class item (SKIP THIS FOR non-AI users)
Left button on an item type in the Inventory menu.
Show slot comments, bring up child instances, etc.

6.3g Change Maximum
Left button on an item type (TELEPHONES)
Choose MAXIMUM when the menu appears.
Enter the maximum number of instances allowed (4).
Show that the maximum number (on the inventory menu) for telephones is 04 instead of 00.
At this point the number of telephone instances in the mission is 4 (the max allowed).
Try creating a telephone (use ADD - 6.3a).

7. Demonstrate Scheduling:

7.1 (mode 6) ;Go to the graphics screen.
(Generate-schedule 'demo)
Upper window shows <u>Power Used</u>
Lower window shows <u>Power Required</u> by load being scheduled
Display BLACKBOARD object in Kb DEMO.
Show FAILED-LOADS slot to show that some loads were not scheduled.
You can also display <u>Power Available</u> in the upper window
To do this, get to the DISPLAY-GRAPH slot on the BLACKBOARD object (being displayed) and change the value to T.
(Generate-schedule 'demo)

8. Show load requirements specification:

8.1 Display 120-V-RADIO-1 object and get to POWER-NEEDED slot.
VALUE: (5509 0 3600 1800 3600)
Here the first number, 5509 (Watts) is the power needed for that load. 0 is the start-time within each period and 3600 (1 hr) is the end-time within each period. 1800 (1/2 hr) is the duration for which the load must be scheduled. And the last 3600 (1 hr) denotes the period.
So the radio will be scheduled every hour for a half hour anywhere within the hour.

8.2 Get to the SCHEDULED slot to show how this was scheduled.
VALUE: (0 3600 7600 ...)
Here we can see that the radio was scheduled at 0 secs, 3600 secs (1 hr), and again at 7600 secs etc.

8.3 Show the power needed as a graph ...
(<u>SCALING</u>
<u>X axis: 0 - all of mission</u>
<u>Y axis: 0 - max power available ; Now 60KW)</u>
(Graph-load '120-V-RADIO-1) ;Graphing a periodic load
Click left button to close.
(Graph-load '50-MAN-TENT-1) ;Graph of a continuous load
Click left button to close.